THE UNIVERSITY OF TEXAS
HEALTHCENTER
AT TYLER

Exercise Physiology and Rehabilitation

February 10, 1992

Mr. Clayton Lee
Lee-Meredith Laboratories
10369 Briar Forest
Houston, Texas 77042-2451

Dear Mr. Lee:

Please find enclosed a copy of the completed manuscript comparing the Orbiter Treadmill to a conventional treadmill. The manuscript was recently accepted for publication in the Journal of Cardiopulmonary Rehabilitation. Thanks for allowing us the opportunity to evaluate the Orbiter.

Sincerely,

J.S. Williams
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OXYGEN COST AND HEART RATE RESPONSE DURING TREADMILL WALKING ON A SOFT PLATFORM BELT

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ABSTRACT

Walking is a common modality used for exercise conditioning and rehabilitation in various groups of individuals. Recently, a new treadmill was designed employing a soft platform belt for the purpose of reducing transmitted foot strike forces. Realizing that energy expenditure differences exist when dissimilar surfaces possessing distinct kinetic characteristics interact with biomechanical movement, we designed a study to evaluate the oxygen cost of exercise performance on this treadmill (TM) which utilizes a soft belt platform design (SBTM). 13 subjects performed two separate tests in a randomized fashion on either the SBTM or a conventional hard platform belt treadmill (HBTM). A modified Balke treadmill protocol was performed in conjunction with open circuit gas collection techniques using four minute stages. Results indicated that the oxygen cost of walking on the SBTM was significantly higher than the HBTM ($p < 0.05$) at each workload investigated within the experimental protocol. Heart rate was significantly higher ($p < 0.05$) at each level as well. In conclusion, TM's of a soft platform belt design may be an alternative exercise training device for certain populations, however, standard equations for predicting energy expenditure from conventional TM's may not apply. In this study, $\dot{V}O_2$ (ml/min) could be predicted with good accuracy from TM time (min) and body weight (kg): $\dot{V}O_2$ (ml/min) = (-1115) + 21.2 (BWkg) + 100 (min) ,$R^2 = .78$.

INTRODUCTION

The motorized-treadmill (TM) has been used extensively as a rehabilitative modality as well as a means of obtaining physiologic data regarding a subject's functional aerobic capacity (1). To date, the majority of these TM's have utilized a basic hard surface platform belt design (HBTM). The forces transmitted across joints while walking on this type of surface can be considerable (2) and may lead to premature termination of the exercise session.

Recently, a TM has been developed which employs a soft platform belt design (SBTM) which may aid in absorbing transmitted foot strike forces. In an unpublished study, foot strike forces were significantly reduced on the SBTM compared to the HBTM (personal communication). What is not known at present is the metabolic cost of walking on this type of surface design.

This study was undertaken to determine the metabolic cost of walking on a new SBTM at exercise intensities commonly used in rehabilitative procedures and general exercise conditioning settings. Second, we compared measured metabolic data ($\dot{V}O_2$) from the SBTM to that predicted from the American College of Sports Medicine speed and elevation equations (3) to determine if these equations were applicable to this new generation TM.

METHODS

Subjects

Thirteen subjects, 7 men and 6 women (age 30.5 ± 6.1 yrs.; Wt. 74.4 ± 20.6 Kg;

HT. 173.4 ± 10.7 cm), performed two separate tests in a randomized order after giving their informed consent to participate in this study in accord with institutional guidelines. Subjects reported to the laboratory in the afternoon to perform TM walking on either the SBTM (Orbiter TM, Lee-Meredith Laboratories, Houston, Texas) or a conventional HBTM (Quinton Q-55, Quinton Instruments Company, Seattle Washington). Manual TM calibrations of speed and grade were performed prior to testing on each treadmill (4). In addition, each subject performed a practice session on the SBTM prior to performing the experimental exercise trial to negate differences in performance which may occur as a result of walking on an unfamiliar surface. Further, hand rail holding per se was discouraged as recommended by Wilson et al. (5) however, the subjects were allowed to rest the palms of their hands on the rails for balance only. Throughout the testing phase, the subjects were cautioned against hand rail holding which would affect the performance outcome measures.

Testing

A modified Balke (5) treadmill protocol was used in this study (Table 1). This walking protocol was selected to minimize differences in $\dot{V}O_2$ attributable to changes in gait and was metabolically similar to the range of performances expected in rehabilitation settings and general conditioning programs. Four-minute stage times were used to insure steady state performance with the last minute of gas collection in each stage analyzed for statistical significance (6,7). Minute to minute gas exchange and electrocardiographic data were used in the regression analysis to investigate statistically significant relationships with increasing workload. Metabolic data was obtained using an automated exercise testing system (Model 2000, Medical Graphics Corporation). Subjects breathed through a low resistance non-rebreathing valve (Model 2700, Hans-Rudolph). Expired gas volume was quantified via integration of the respiratory flow signal from a pneumotachometer (Model 3813, Hans-Rudolph) coupled with a pressure transducer (Model 45-1-871, Validyne Engineering Corporation). Routine volume calibration was accomplished with a 3.0 liter calibration syringe. Expired 0_2 and CO_2 fractional concentrations were obtained via a fuel cell analyzer (Model S-3A/I, Applied Electro Chemistry) and an infrared absorption analyzer (Model CD-102, Datex Instruments), respectively. Gas analyzers were calibrated with a certified calibration reference gas mixture (16 percent O_2, 6 percent CO_2). From these measurements oxygen consumption ($\dot{V}O_2$ ml/kg/min) and carbon dioxide production ($\dot{V}CO_2$ l/min) were calculated.

Heart rate (HR) was continuously monitored via electro-cardiography (Q-2000, Quinton Instruments) using standard limb leads and a modified V_5 chest lead (CM_5). Heart rate data was electronically relayed to a Tektronix 4052 computer (Tektronix, Inc.) on a breath-by-breath basis. All respiratory measurements were continuously monitored on a breath-by-breath basis with the last 30 seconds of each minute stage averaged and expressed on a per minute basis. All subjects were able to complete the testing protocol without difficulty.

Statistical Methods

Descriptive statistics were generated for the dependent variables. A one-way repeated analyses of variance was used to determine significant differences in O_2 uptake for the two TM designs at the completion of each stage of exercise. Paired T-tests were used to determine where significant differences in O_2 uptake occurred with respect to treadmill stage. Multiple linear regression analysis was performed to investigate the relationship of $\dot{V}O_2$ to work or time of exercise for the SBTM. Statistical significance was established at the 0.05 level. All statistical analysis were performed using a statistical analysis system (SAS) for the personal computer. (SAS 6.06, Statistical Analysis System).

Results

Seven males and 6 females with a mean age of 30.5 ± 6.1 years completed the study. Males, on the average were 30 kg heavier and 20 cm taller than the females tested. Both males and females participated in the experimental protocol; however, since each subject served as their own control, separate statistical analysis were unnecessary. No significant differences in resting $\dot{V}O_2$ (ml/kg/min) or HR (bpm) were detected between the two experimental trials ($p > 0.05$).

As work rate was incremented from resting to the peak levels of exertion elicited by the experimental protocol, statistically significant differences ($p < 0.05$) in $\dot{V}O_2$'s were obtained. These data are depicted in Figure 1. As noted in Figure 1, the slope of the oxygen uptake line (ml/kg/min) remains equivalent for the SBTM vs the HBTM as work is incremented through the range of workloads tested ($p > 0.05$). However, the $\dot{V}O_2$

intercept was significantly greater for the SBTM design ($p < 0.05$) and this accounted for the differences noted at each level of exertion tested. Heart rate (bpm) was significantly higher ($p < 0.05$) for the SBTM as compared to the HBTM at each level of exertion tested (Table 2).

As significant differences in $\dot{V}O_2$ were present between the SBTM and HBTM, a linear regression model was derived to predict $\dot{V}O_2$ while walking on the SBTM. Variables included in the regression model were treadmill time in minutes and body weight in kilograms. A significant linear relationship was noted with the following equation derived for predicting $\dot{V}O_2$ in ml/min:

$$\dot{V}O_2 \text{ ml/min} = (-1115) + 21.2 \text{ (BWkg)} + 100 \text{ (min)}$$

This equation accounted for 78% of the variance in $\dot{V}O_2$ and was reflected by an $r = .88$. No statistically significant curvelinear model could be found for the $\dot{V}O_2$ data analyzed.

DISCUSSION

The results of this study demonstrate that there are significant differences ($p < 0.05$) in energy expenditure between walking on a soft platform belt design TM vs. a conventional hard platform belt. Differences in $\dot{V}O_2$ are the result of platform design with the SBTM design requiring an additional oxygen cost of approximately 5.0 ml/kg/min from the onset. (Figure 1) Significant differences ($p < 0.05$) in heart rate were also present between the two treadmill belt designs. While a slight increase in $\dot{V}O_2$ was noted for the SBTM at each level of exertion, this departure was not statistically significant ($p > 0.05$), i.e., slope of the regression lines are equivalent. However, if the protocol was extended to include running and/or a significant change in gait pattern, significant divergence of the regression lines may well occur and the linear relationship as noted in this study may not exist. Further, data from this study suggest that energy expenditure can be estimated with good accuracy from body weight (kg) and TM time (min) within the ranges of speed and grade investigated in this study.

Oxygen uptake differences are known to exist when dissimilar surfaces with distinct kinetic characteristics interact with biomechanical movement (8,9). Specifically, those surfaces which have increased compliance will elicit greater energy expenditures. Therefore, the higher energy costs and HR's while walking on the SBTM were not surprising. Balke (10) has previously described a formula for estimating the oxygen cost of walking on a smooth hard surface. This formula considered the work involved in the vertical, up and down movement of the body with each stride. Increased belt compliance, as seen with this surface design, should result in larger vertical movements per stride which will increase the oxygen cost accordingly. In the present study, the higher energy cost of walking on the SBTM could be attributed to increased vertical work secondary to the greater compliance of the belt.

Minitrampoline walking or jogging constitutes an activity performed on a similar surface design to that of the SBTM. In a previous study investigating minitrampoline exercise, Atterbom and Maclean (11) compared the impact of stepping frequency on the metabolic cost of stationary jogging on a minitrampoline with stationary jogging on a tiled floor. Though no significant differences between the two modes of exercise were observed in $\dot{V}O_2$ (ml/kg/min) at 80 steps/min, the $\dot{V}O_2$ was significantly higher at 120 steps/min on the minitrampoline for the male subjects compared to female subjects. This difference was attributed to the inability of the female subjects to maintain a paced rhythm which resulted in a tendency to "ride" the trampoline and improve efficiency. Ballard et.al. (12) compared walking and running on the treadmill and minitrampoline at equivalent stepping frequencies in male subjects. In agreement with the present study, $\dot{V}O_2$ (ml/kg/min), HR (bpm) and systolic blood pressure (mm Hg) were significantly higher for the minitrampoline activity as compared to treadmill performance. More recently, Gerberich et al (13) studied the acute effects of rebound exercise in sedentary women with increasing rates of jogging steps or bounces per minute on a minitrampoline. Interestingly, mean values for $\dot{V}O_2$ and HR decreased while progressing from 90 to 140 bounces/min though an inverse relationship between energy expenditure and ratings of perceived exertion was observed during incremental bouncing. Similar to the finding of the present study, $\dot{V}O_2$ and heart rate increased with an increasing rate of jogging steps.

The present data also support the earlier findings of Hartung and Kirby (14) in which $\dot{V}O_2$ increased steadily as walking cadence was incremented on a minitrampoline in normals as well as patients with cardiac disease. In their study, jogging rates of 60, 75 and 90 steps per minute yielded $\dot{V}O_2$'s of 16.7, 18.6, and 21.2 ml/kg/min, respectively. While direct comparison of the data of Hartung and Kirby (14) as well as the previously cited investigations cannot be made to the present study, the trend of increasing work performance to increasing oxygen cost is similar. Further, within the range of workloads studied, the response of $\dot{V}O_2$ and heart rate to work on the SBTM was similar to that of the traditional hard surface treadmill with the exception of an incremental oxygen cost that was incurred at the onset of exercise. This incremental oxygen cost of walking on the SBTM can be attributed to the kinetic nature of the belt surface and differences in muscle recruitment and force of contraction of the specific muscles involved.

As suggested by Pollock, (15) a training instrument must be capable of eliciting a specific increase in $\dot{V}O_2$ and heart rate. The results of the present study demonstrated that at the workloads tested, predictable oxygen consumption requirements are achievable. In prescribing exercise, it is of paramount importance that work intensity be assigned appropriately for different individuals. Knowledge of the required energy expenditure for the particular training device is therefore essential. As depicted in Table 2, the ACSM $\dot{V}O_2$ prediction equations significantly underestimate the actual oxygen cost for walking on the SBTM utilized in the present study. The derived regression equation in this study provides a good estimate of oxygen cost (R^2 = .78) for walking on the SBTM within the range of workloads tested.

In summary, the oxygen cost of walking on a SBTM is significantly higher than walking on a conventional hard platform type TM at equivalent speeds and grades. Throughout the speed/grade range studied, $\dot{V}O_2$ and heart rate followed a linear path. Standard prediction equations for estimating energy cost from speed and grade on a conventional TM surface significantly underestimate the actual energy cost for equivalent workloads on the SBTM. The SBTM is able to deliver quantifiable workloads within the speed and grades studied and this device may be an alternative training device for certain populations; however, the exercise intensity should be prescribed accordingly. Our data suggests the $\dot{V}O_2$ can be accurately estimated for walking on the SBTM using a simple regression equation.

Table 1. Experimental Treadmill Protocol

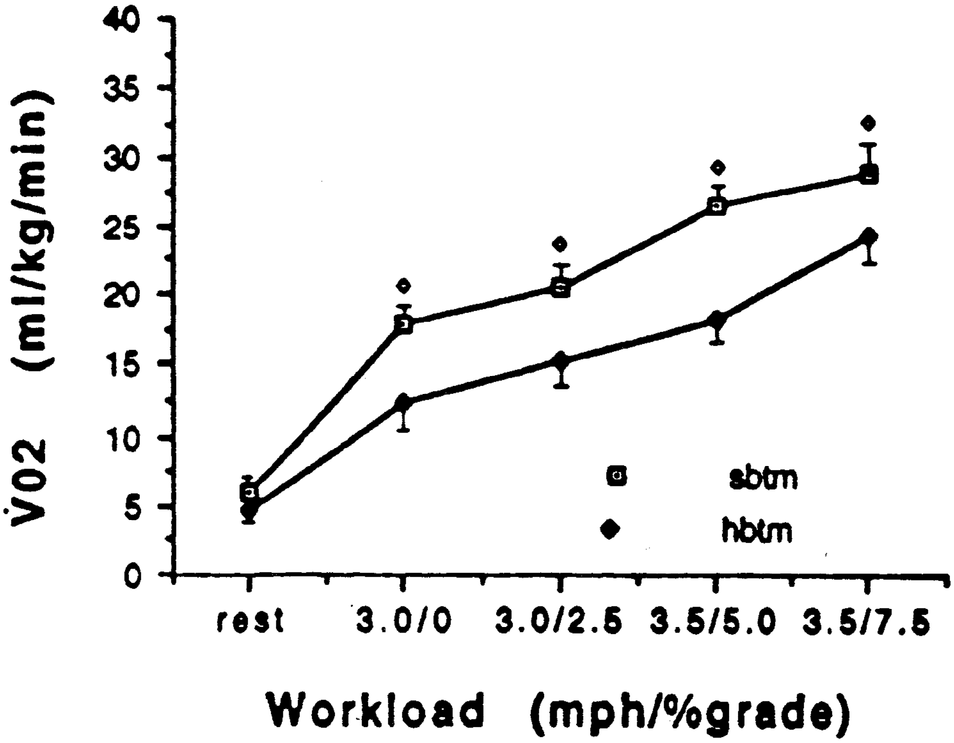
Stage	Speed (MPH)	Grade (%)
1	3.0	0.0
2	3.0	2.5
3	3.5	5.0
4	3.5	7.5

Table 2.

Variable	Treadmill	Workload (MPH/% Grade) 3.0/0.0	3.0/2.5	3.5/5	3.5/7.5
$\dot{V}O_2$ (ml/kg/min)	SBTM	17.8 ± .70*	20.4 ± 1.2*	26.4 ± 1.1*	29.0 ± 1.7*
	HBTM	12.5 ± 1.3	15.2 ± 1.2	18.3 ± 1.0	24.5 ± 1.4
	ABS Diff.	5.3	5.2	8.1	0.45
HR (bpm)	SBTM	106 ± 4*	117 ± 4*	129 ± 4*	141 ± 5*
	HBTM	98 ± 3	106 ± 3	115 ± 3	128 ± 3
	ABS Diff.	8	11	14	13
ACSM $\dot{V}O_2$ (ml/kg/min)		11.6	15.1	21.4	25.6

* SBTM significantly ($p < 0.05$) higher than HBTM

LIST OF FIGURES



40
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V02 (ml/kg/min)
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3.0/2.5
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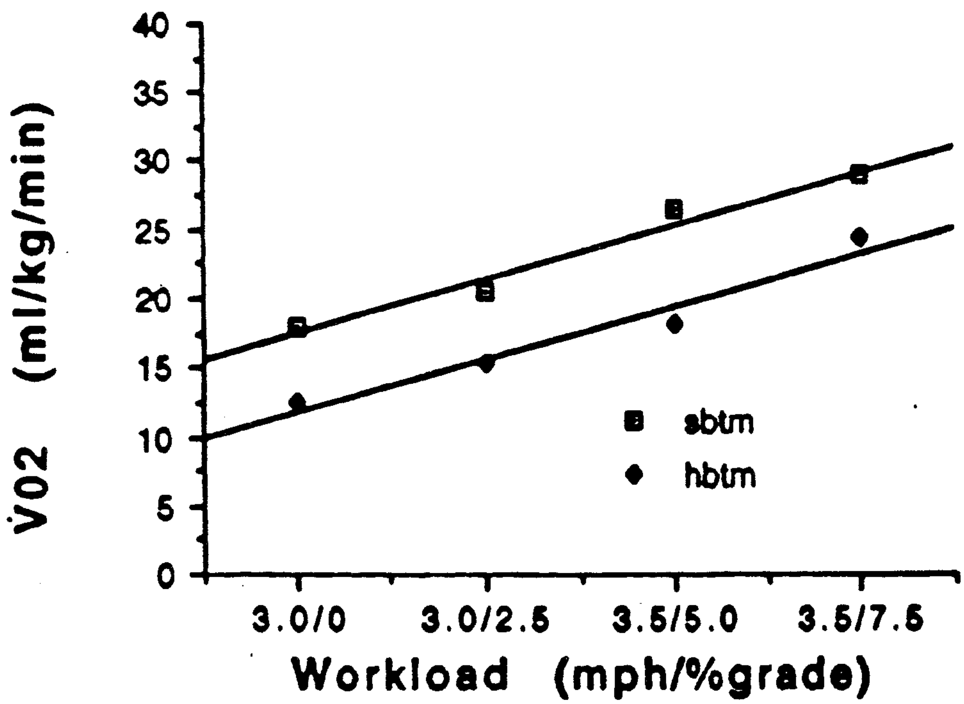
3.5/7.5
Workload (mph/%grade)



40
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3.5/5.0
3.5/7.5
Workload (mph/%grade)

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